PROBLEM ANALYSIS FOR INVESTIGATION OF THE EFFECTS OF TIMBER MANAGEMENT ON THE PRODUCTION OF NONTIMBER FOREST RESOURCES

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NONTIMBER FOREST RESOURCES

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<u>FINAL REPORT</u>

LINEAR PROGRAMMING--OPTIMIZATION

STATE OF THE ART

Analysis of multiresource production opportunities can be carried out by constructing and applying mathematical programming models. Given the state of the art, linear programming is generally the only technique that can be used pragmatically as the fundamental building block for optimization in the assessment analysis. A simplified linear programming model considering only two types of land, five management prescriptions, and three resources will be used to illustrate the key points (Figure 6). This type of model directly reflects the management prescription orientation of the matrix structure (Figure 4). Also, it describes the lowest level of analysis. A multi-level approach will be discussed in the next section.

This overly simple model ignores time dimensions and other complexities such as non-constant benefit coefficients. Environmental quality indexes are also excluded from the example. These complexities do not pose severe analytic problems, and they can be brought into the analysis without conceptual difficulty--though such a model would be significantly larger (i.e., more rows and columns).

In Figure 6, the major column headings are types of land and/or resources. The "X_is" under the two land types are the number of acres allocated to alternative management prescriptions which could be applied in TYPE I (X_1 and X_2) and TYPE II (X_3, X_4, X_5) land. X_1 through X_5 are variables defined as the number of acres allocated to the given management prescription (1 through 5).

	Type I		Type II			Products			Constraint type	RHS
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8		
Timber	$A_{1,1}$	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$	$A_{1,5}$	$-A_{1,6}$			$=$	$K_1 = 0$
Wildlife	$A_{2,1}$	$A_{2,2}$	$A_{2,3}$	$A_{2,4}$	$A_{2,5}$		$-A_{2,7}$		$=$	$K_2 = 0$
Forage	$A_{3,1}$	$A_{3,2}$	$A_{3,3}$	$A_{3,4}$	$A_{3,5}$			$-A_{3,8}$	$=$	$K_3 = 0$
Budget	$A_{4,1}$	$A_{4,2}$	$A_{4,3}$	$A_{4,4}$	$A_{4,5}$				$\leq$	K_4
TYPE I	$A_{5,1}$	$A_{5,2}$							$=$	K_5
TYPE II			$A_{6,3}$	$A_{6,4}$	$A_{6,5}$				$=$	K_6
TIMBER OUTPUT						$A_{7,6}$			$\geq$	K_7
WILDLIFE OUTPUT							$A_{8,7}$		$\geq$	K_8
FORAGE OUTPUT								$A_{9,8}$	$\geq$	K^9
NET BEN.	$A_{10,1}$	$A_{10,2}$	$A_{10,3}$	$A_{10,4}$	$A_{10,5}$	$A_{10,6}$	$A_{10,7}$	$A_{10,8}$		

Figure 6. A simple resource allocation model where X_1 and X_2 are the number of acres in Type I land allocated to alternative management prescriptions; X_3, X_4, X_5 are the number of acres in Type II land allocated to alternative management prescriptions; X_6, X_7, X_8 are timber, wildlife, and forage products, respectively; the A_{ij} are production coefficients; the $A_{10,j}$ are the objective function coefficients; and the K_i are the right hand sides (RHS).

The timber, wildlife and forage rows in the matrix represent the resource outputs of this forest system which result from implementation of the management prescriptions. The land, TYPE I and TYPE II, rows are the inputs (acres) to this "joint production system." K_5 acres of Type I land are available, and K_6 acres of Type II land are available.

The timber output, wildlife output, and forage output rows are the actual amounts of each of the outputs that are harvested from the forest system. The "Net Ben." row is the objective which managers seek to maximize given the resources available and the production relationships involved.

The "Xs" under the major column heading PRODUCTS ($X_{6,7,8}$) are accounting columns which collect or transform the outputs described in some of the rows into an aggregate output for the area being analyzed.*

The A_{ij}s in columns 1-5 can generally be termed the impacts of the jth management prescription on either the row outputs or row inputs. For example, $A_{1,1}$ is the output of timber per acre if the first management prescription is implemented, and $A_{5,1}$ is the amount of Type I land it takes to implement the minimum size prescription one treatment.

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*K_1 through K_3 are set at zero to force all product output levels into X_6, X_7, and X_8.

The coefficients in row 10, the "Net Ben." row, describe the change in net benefits if one unit of the ith management prescription occurs. Thus, $A_{10,1}$ is the cost of prescription 1 and $A_{10,6}$ is the benefit derived from one unit of timber output (X_6).

K_4, is an upper limit on the amount of money to be made available for managing the area. K_7 through K_9 are minimum levels of timber, wildlife, and forage that are required.

The tasks which must be completed to formulate the data suggested by Figure 8 are:

1. Classification of the land base into relatively homogenous subunits for which production functions may be estimated.

2. Specifications of the alternative management prescriptions for each subunit.

3. Specification of the multiresource yields and environmental impacts through time associated with each prescription.

4. Specification of prescription inputs.

5. Specification of input and output costs and benefits.

6. Specifications of all additional constraints (i.e., minimum timber flow, maximum sediment flow, etc.), including those that reflect social consideration.

AN INTEGRATED MODEL RECOMMENDED FOR THE 1990 ASSESSMENT

Given the state-of-the-art in accounting for ecological, economic, and social considerations, the problem is to efficiently allocate resources (land, labor, and capital) so as to optimally provide products for human benefits, subject to the biological capability of the ecosystems involved, without reducing that biological capability over time, and without inducing unacceptable social impacts as measured by a set of "social indicators."

The previous section outlined a basic model structure that attacks this sort of problem. The difficulty of scope remains, however. On the one hand, modeling relatively small areas of land (such as a National Forest) is appealing because of the relative detail, resolution, and accuracy that can be achieved. On the other hand, regional and National concerns are different than local concerns and joint prescriptions between small land units may be highly desirable. The need for centralized decisionmaking is a primary motivation for national planning efforts such as RPA.

The ideal resolution of this dilemma would be the use of a National optimization model that is also capable of achieving high levels of resolution and detail. Because this is technically impossible at this time, a multi-level modeling approach is suggested here. This approach attempts to combine National and regional discretion, small scale resolution and detail, and consistency between different levels of planning.

Work by Wong (1979) on U.S. Forest Service Region 3 provides an excellent start for the modeling approach suggested here. In general, he proposes that Regional and National models should not directly consider land management practices, but rather choose from alternative management plans. These alternatives would be developed at the land unit level for the Regional model and at the Regional level for the National model. Each alternative management plan would be associated with a different budget (level of investment) or, possibly, with different policy constraints (such as wilderness emphasis, mandated stewardship-level management intensity, fiber production emphasis, etc.).

Figure 8 portrays the basic structure of the multilevel model. In Figure 8, it is important to note the information carried in the "Alternative Management Plans." Each alternative is specified by all associated resource output levels and all operating costs (budget requirement) anticipated. A more precise description of the model structure suggested is presented in Appendix I.

It should be made clear that the ecological production information enters the problem at the first, land-based level. The economic information, especially supply (cost) and demand (benefit) information can be utilized at all levels, as is analytically feasible. And, social information can be used to constrain model solutions at any level so as not to violate critical social concerns applying to the social indicators discussed above. As mentioned above, different types of social concerns apply at different levels of analysis. The model structure depicted in Figure 8 is quite conducive to such a situation.

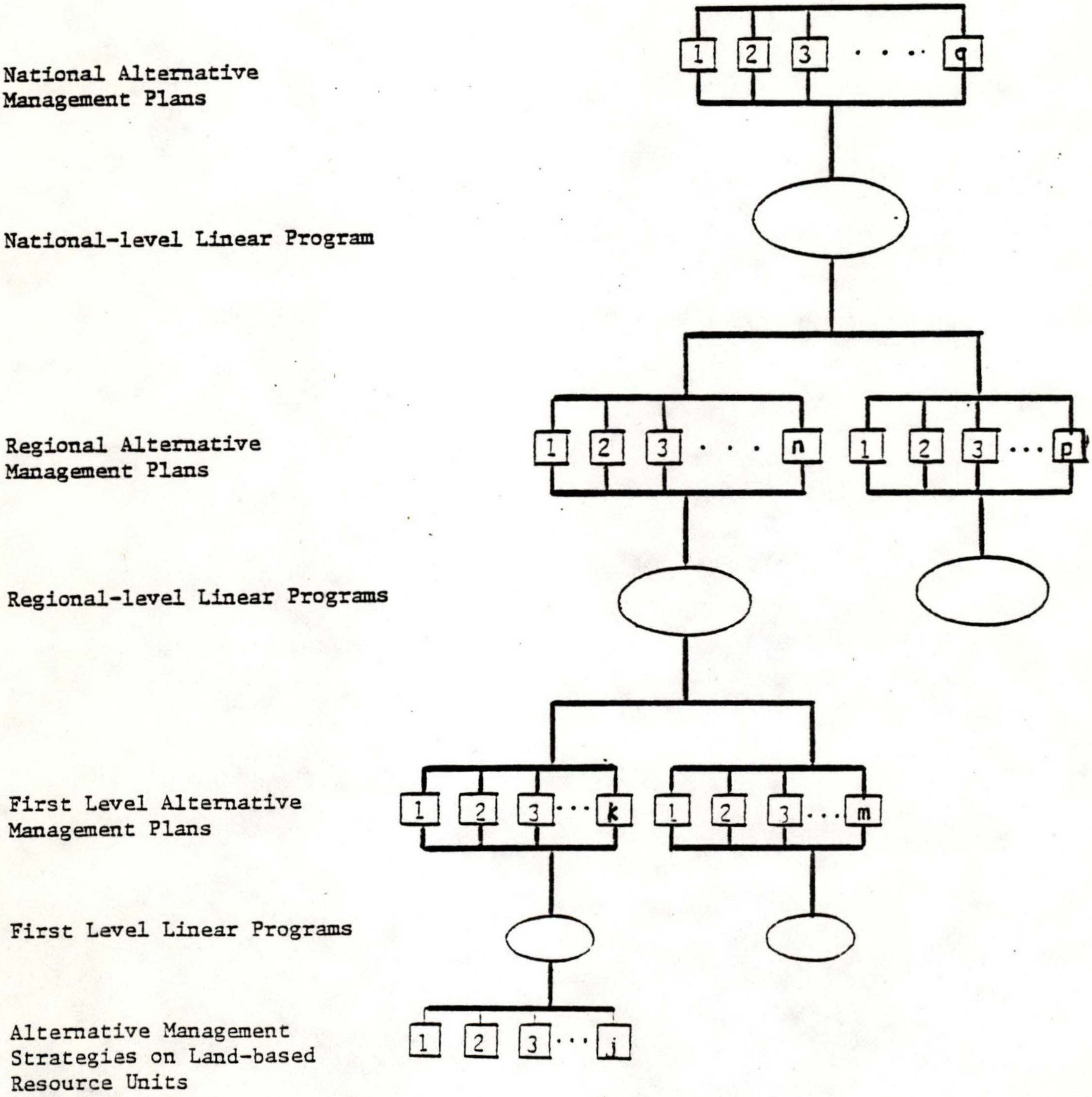

Figure 8. Multilevel model of the Forest Service planning process (from Wong, 1979).

The multi-level modeling structure proposed here for the 1990 Assessment is shown in Figure 9. The lowest level of analysis occurs at the National Forest level where the Forest System Production Possibilities Generator ($FPPG_{i,j}$) is used to define production possibilities for each Forest within each Region. In the FPPG, acre by acre land allocations are made for those land units under Forest Service control.

Since specific land allocations on non-Forest system lands are not within the control of the Forest Service, it seems reasonable that the modeling effort on these lands for the 1990 Assessment need not involve the detail and level of resolution that the FPPG models facilitate. One model for each region for non-Forest System lands, $NPPG_i$, would construct a general "picture" of opportunities on these lands. Similar to FPPG, the NPPG would allocate land units to management prescriptions, but on a much broader scale. The FPPG and NPPG models are of the type depicted in Figure .

Forest System and non-Forest System lands are treated separately until the regional model. Joint prescriptions between the F.S. and other ownerships (other Federal, state and private) within each region would be analyzed in the Regional Alternative Generator models, RAG_i. The inputs to RAG_i from the Forest System Production Possibilities Generator and from the non-Forest System Production Possibilities generator would be resource output levels, environmental quality indices, and operating costs (budget requirements) associated with selected management prescriptions.

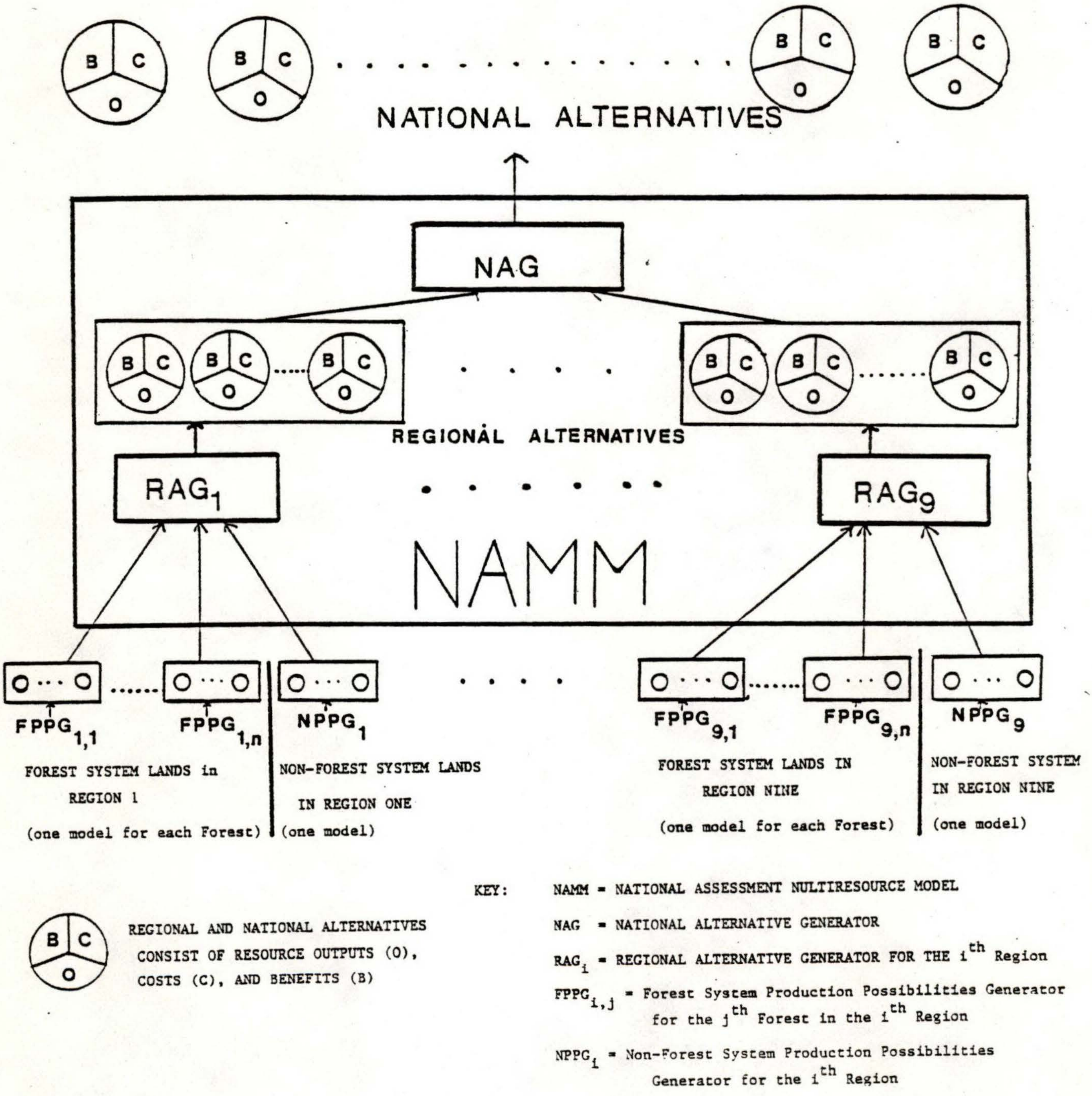

Figure 9. Multi-level modeling structure proposed for the 1990 Assessment analysis.

Regions are treated separately until the National model. Joint prescriptions between regions would be analyzed in the National Alternative Generator, NAG. The inputs to NAG from the regional models, RAG_j, would be resource output levels, environmental quality indices and operating costs (budget). Acre by acre land allocations occur only within the Forest System Production Possibilities Generator, $FPPG_{i,j}$ and the non-Forest System Production Possibilities Generator, $NPPG_j$.

Within the NAG and RAG models, management alternatives are evaluated in entirety - they are either accepted or rejected in total. Parts of the management alternatives for a Forest in a RAG or a region in a NAG are not considered. This points up the need for a sufficient number of alternatives to be generated.

The NAG assumes independence between regions, and the RAG's assume independence between Forest System and non-Forest System lands. That is, management actions in one land unit are assumed not to affect the production possibilities in another land unit. Ecologically, this may not be the case, for example, migrating bird populations might be enhanced through coordinated habitat management on a given flyway. This information can be included in the model structure depicted in Figure 9 , if it becomes available.

The suggested models for the FPPG are the FORPLAN models currently being developed in the Land Management Planning effort. The suggested models for the NPPG are revised versions of the NIMRUM regional models (Ashton, et al., 1980). The model structure for the RAG's and the NAG

would essentially be the same, and this structure remains to be developed fully. Validation of the production information in the FORPLAN and NIMRUM models is identified as a high priority research problem because of the importance of that information in the NAMM structure as a whole.

Figure 10 depicts the linear programming matrix of a very simple version of a NAG type of model. In this example, only two regions, two alternatives, and three products are included. Also, only one time period is included, and embellishments such as regional targets are not included. Expansion beyond the dimensions of this simple example is straight forward, and as noted elsewhere, this type of problem is conducive to non-linear solution techniques (implicit enumeration, dynamic programming) if particular conditions (such as between-region interactions) make it necessary.

In Figure 10, the X_1 through the X_8 are 0-1 variables representing selection or rejection of an alternative output vector (with associated benefits and costs) for a given region and ownership. For example, X_1 represents selection or rejection of the entire output vector $A_{1,1}$; $A_{2,1}$; $A_{3,1}$; in Forest System region 1. All of the matrix below the NET BEN. (objective function) row constrain the X_1 through X_8 so that each of them is between 0 and 1, and so that only one alternative can be selected for each region and ownership. Rows 5 through 7 set National "targets" on the three outputs. Row 4 places a budget constraint on the selection of alternatives, and row 8 is the objective function to be maximized.

	Forest System Region 1		Non-Forest System Region 1		Forest System Region 2		Non-Forest System Region 2		Products			Constraint type	RHS
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}		
Timber	$A_{1,1}$	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$	$A_{1,5}$	$A_{1,6}$	$A_{1,7}$	$A_{1,8}$	$-A_{1,9}$			$=$	$K_1=0$
Wildlife	$A_{2,1}$	$A_{2,2}$	$A_{2,3}$	$A_{2,4}$	$A_{2,5}$	$A_{2,6}$	$A_{2,7}$	$A_{2,8}$		$-A_{2,10}$		$=$	$K_2=0$
Forage	$A_{3,1}$	$A_{3,2}$	$A_{3,3}$	$A_{3,4}$	$A_{3,5}$	$A_{3,6}$	$A_{3,7}$	$A_{3,8}$			$-A_{3,11}$	$=$	$K_3=0$
Budget	$A_{4,1}$	$A_{4,2}$	$A_{4,3}$	$A_{4,4}$	$A_{4,5}$	$A_{4,6}$	$A_{4,7}$	$A_{4,8}$				$\leq$	K_4
TIMBER OUTPUT									$A_{5,9}$			$\geq$	K_5
WILDLIFE OUTPUT										$A_{6,10}$		$\geq$	K_6
FORAGE OUTPUT											$A_{7,11}$	$\geq$	K_7
NET BEN.	$-A_{8,1}$	$-A_{8,2}$	$-A_{8,3}$	$-A_{8,4}$	$-A_{8,5}$	$-A_{8,6}$	$-A_{8,7}$	$-A_8$	$A_{8.9}$	$A_{8,10}$	$A_{8,11}$		
0-1	1											$\leq$	1
Model		1										$\leq$	1
Constraints			1									$\leq$	1
				1								$\leq$	1
					1							$\leq$	1
						1						$\leq$	1
							1					$\leq$	1
								1				$\leq$	1
	1	1										$=$	1
			1	1								$=$	1
					1	1						$=$	1
							1	1				$=$	1

Figure 10. A simple 0-1 NAG model, where the X_1 through X_8 are 0-1 variables representing selection or rejection of an output vector $A_{i,1}$ through $A_{i,8}$ (i=1,3) respectively, the $A_{8,j}$ are the objective function coefficients, and the K_1 through K_7 are right hand sides (RHS).

If the model depicted in Figure 10 were a RAG model, then instead of "Forest System Regions," the model would have a number of Forests and the non-Forest Systen land unit in the given region. Refering back to Figure 6, the output vectors in a given RAG would be the solution values of the Products (X_6, X_7 and X_8 in Figure 6) in the lowest level models. For example, the $A_{1,1}$; $A_{2,1}$; and $A_{3,1}$ in Figure 10 would be the first alternative solution values of X_6, X_7, and X_8 in Figure 6 for the first National Forest.

Since this is a linear programming model instead of a discrete optimization model, the X_1 through X_8 may actually take on solution values between 0 and 1 but not equal to either. For example X_1 and X_2 in Figure may solve with values of .6 and .4 respectively. This is interpreted as a partial acceptance of each alternative which may or may not be feasible. This may suggest the construction of a new alternative that is subjectively constructed for X_1 and X_2, based on the solution values. No assurance can be made, however, that this new alternative will be completely accepted. Its presence may actually cause changes in the solution values of any or all other variables as well. Resolution of this problem/question is left as a research need in the development of NAMM.

Finally, this modeling structure need not be static. The choice variables at all levels can be linked to different time periods and the solution will thus include scheduling choices. The linear programs (FORPLAN) being developed in the Forest Planning effort are so structured. The possible conversion of NIMRUM to handle scheduling problems (and the desirability of such conversion) is left as a research need.

Advantages and Disadvantages of the NAMM Structure

Advantages:

1.) It can accommodate decision making at a number of different levels. This is important when attempting to account for considerations such as social impacts that are often not conducive to aggregation into a National analysis.

2.) It can incorporate, as the state-of-the-art allows, ecological, economic, and social information.

3.) It is of very workable size and complexity at the regional and National levels. This is the case because the choice variables at these levels are defined as selection among discrete alternatives. In the National model, for example, with 9 regions and, say, 10 alternatives per region, only 90 choice variables are implied.

4.) It solves the problem of disaggregating National analysis results across smaller land units.

5.) It avoids problems of inconsistency between levels of analysis which would occur if these analyses were performed independently.

6.) It provides for production possibilities analysis to occur at the lowest level where a relatively high degree of resolution is possible, while at the same time preserving discretion at higher levels of decision-making.

7.) It can utilize existing or soon to be available production-oriented models (FORPLAN and NIMRUM).

Disadvantages:

1.) Limiting the choice variables at the regional and National levels to selection from a finite number of alternatives may cause the analysis to overlook desirable options that are, in fact, feasible.

2.) In limiting most of the production possibilities analysis to the lowest level of analysis, some interaction effects between land units may be ignored. Examples of these effects are: enhanced migratory bird populations resulting from coordinated habitat management on a given flyway; and down stream water quality effects resulting from timber harvesting. If these effects can be predicted quantitatively, then they could be included in the National and regional models in NAMM.

APPENDIX I RIGOROUS DESCRIPTION OF NAMM

Define:

Y_{ij} = output matrix for $i^{\underline{th}}$ land unit and the $j^{\underline{th}}$ management ~ timber, range, fish and wildlife, recreation, and water production, for each time period.

$\underset{\sim}{X}_{ij}$ = input matrix for the $i^{\underline{th}}$ land unit and the $j^{\underline{th}}$ management alternative. Each input matrix contains the land, labor, capital, and management requirements associated with the alternative (Y_{ij}), for each time period.

$\underset{\sim}{X}_{ij}$ and $\underset{\sim}{Y}_{ij}$ each come from the first level linear programs.

$B_{F,R,N}$ = the benefit function at the forest, ergional, and national level, respectively.

$C_{F,R,N}$ = the social cost function at the first, regional, and national level, respectively.

$C^{o}_{F,R}$ = the operating cost function at the first and regional level, respectively. A $C_F{}^{o}(\underset{\sim}{X}_{ij})$ is, for example, the operating cost requested by a first level land unit to pay for the given X_{ij} in producing the $\underset{\sim}{Y}_{ij}$.

$Y_{\kappa t}$ = the $\kappa = 1$, n outputs included in the output matrix $\underset{\sim}{Y}_{ij}$, for time period t.

$X_{\ell t}$ = the $\ell = 1$, m inputs included in the input matrix $\underset{\sim}{X}_{ij}$, for time period t.

F = the production function relating $Y_{\kappa t}$ and $X_{\ell t}$. This is represented in a linear program by the A-matrix.

$FT_{\kappa t}$ = first level target on the $\kappa^{\underline{th}}$ output, in time period t.

$RT_{\kappa t}$ = regional target on the $\kappa^{\underline{th}}$ output, in time period t.

$NT_{\kappa t}$ = national target on the $\kappa^{\underline{th}}$ output, in time period t.

I_{Ft}, I_{Rt}, I_{Nt} = the investment intensity (Budget) for first, regional, and nattional level, respectively, at time t.

$\underset{\sim}{Y}_{pq}$ = output matrix for the $p^{\underline{th}}$ region and the $q^{\underline{th}}$ regional alternative.

$\underset{\sim}{X}_{pq}$ = input matrix for the $p^{\underline{th}}$ region and the $q^{\underline{th}}$ regional alternative.

<u>$i^{\underline{th}}$ first level problem</u>

Maximize:

$$\sum_{\kappa}\sum_{t} \beta_F\,(Y_{\kappa t}) - \sum\sum C_F\,(X_{\ell t})$$

$$\text{S.T.}\quad Y_{\kappa t} \le F(X_{\ell t})$$

$$\sum_{\ell} C^{o}{}_{F} X_{\ell t} \le I_{Ft} \quad t = 1,\ t^{o}$$

$$Y_{\kappa t} \ge FT_{\kappa t} \qquad \begin{array}{l} t = 1,\ t^{o} \\ k = 1,\ n \end{array}$$

For the $j^{\underline{th}}$ set of I_{ft} and $FT_{\kappa t}$ the solution to this problem yields a $\underset{\sim}{Y}_{ij}$ and $\underset{\sim}{X}_{ij}$. By systematically varying the I_{Ft} and $FT_{\kappa t}$ across the alternatives, the regional choice variables $(\underset{\sim}{Y}_{ij})$ will represent a reasonable range of discretion.

<u>$p^{\underline{th}}$ Regional Problem</u>

Select one $\underset{\sim}{Y}_{ij}$ for each of the first level land units so as to maximize:

$B_R(\underset{\sim}{Y}_{ij}) - C_R(\underset{\sim}{Y}_{ij})$ subject to: $\Sigma C^{o}{}_{F}(\underset{\sim}{X}_{ij}) \le I_R$

constraints

$$\sum_{i} Y_{\kappa t} \ge RT_{\kappa t} \quad \kappa = 1,n$$

$$t = 1,\ t^{o}$$

The selection of a $\underset{\sim}{Y}_{ij}$ is a discrete (0-1) decision. Thus, the problem will be solvable with an integer program, 0-1 program, or dynamic program. The $B_R(\underset{\sim}{Y}_{ij})$ and $C_R(\underset{\sim}{Y}_{ij})$ can include any interaction or nonlinearity that we are able to identify. The C_F amounts to a budget request for a given $\underset{\sim}{X}_{ij}$ in producing a $\underset{\sim}{Y}_{ij}$.

Systematic variation in I_R and RT_K would result in q alternatives for each p region. The solution for given levels of I_R and the RT_K's for a given region would result in a selected alternative $\underset{\sim}{Y}_{ij}$ and $\underset{\sim}{X}_{ij}$ for each first level land unit. If we aggregate timed outputs and inputs across the land units, then we can create a new output matrix ($\underset{\sim}{Y}_{pq}$) and input matrix ($\underset{\sim}{X}_{pq}$) for each regional alternative. These are then the choice variables at the national level.

<u>National Problem</u>:

Select one $\underset{\sim}{Y}_{pq}$ for each of the Regions so as to maximize:

$$B_N(\underset{\sim}{Y}_{pq}) - C_N(\underset{\sim}{Y}_{pq}),$$

Subject to:

$$\sum_p C_R(\underset{\sim}{X}_{pq}) \leq I_N$$

$$\sum_p Y_{\kappa t} \geq NT_{\kappa t}; \; \kappa = 1,n$$
$$t = 1,\, t^{o}$$

plus any desired policy constraints. If this model is run without the budget constraint (I_n), then the operating costs ($\sum_p C_R$) associated with that unfettered maximization of net benefits would be a Pareto efficient solution at the national level. This model is also a discrete (0-1) choice model that can include any nonlinear or interactive specification of B_N and C_N which is identifiable.

APPENDIX IV: INTEGRATING FUNCTIONAL ANALYSES

The National Resource Analysis Techniques project has an explicit charter to conduct research in three functional problem areas (timber, forage, and wildlife and fish) as well as in a multiresource problem area. This reflects the probable organization of work on the 1990 Assessment--functional efforts being carried out independently and then somehow "integrated" in a multiresource planning effort. The purpose of this section is to discuss the integration of work carried out separately in functional areas into a multiresource analysis. This is important both for structuring work within this Research Work Unit and for providing a mechanism for putting together available data generated from functional orientations.

Figure 12 depicts the production matrix structure. This matrix simply indicates that the production information required for any given "type" of land is the expected outputs of timber, forage, wildlife and fish, recreation, water, and environmental quality outputs that would result from different potential management prescriptions (one of which would be no management). This production matrix provides a logical method of utilizing functional analyses for multiresource analysis and planning.

	Management prescriptions				
Output	S_0	S_1	S_2	. . . . . .	S_k
Products					
Q_1	$X_{1,0}$	$X_{1,1}$	$X_{1,2}$		$X_{1,k}$
Q_2	$X_{2,0}$	$X_{2,1}$	$X_{2,2}$		$X_{2,k}$
.					
.					
Q_n	$X_{n,0}$	$X_{n,0}$	$X_{n,2}$		$X_{n,k}$
Environmental Quality Outputs					
Q_{n+1}	$X_{n+1,}$	$X_{n+1,1}$	$X_{n+1,2}$		$X_{n+1,k}$
Q_{n+2}	$X_{n+2,0}$	$X_{n+2,1}$	$X_{n+2,2}$		$X_{n+2,k}$
.					
.					
Q_m	$X_{m,0}$	$X_{m,1}$	$X_{m,2}$	. . . .	$X_{m,k}$
output vectors	$\tilde{Q}_0$	$\tilde{Q}_1$	$\tilde{Q}_2$		$\tilde{Q}_k$

Figure 12. Ecosystem outputs under alternative management prescriptions.

Each row in the production matrix can be determined separately (in functional analyses) if three assumptions hold:

(1) The same alternative management prescriptions are analyzed in each row. Unless this is true, the matrix will be incomplete. Traditionally, functional analyses of single resource outputs have concentrated only on management prescriptions that are directly oriented towards a single resource. In order for the functional production analysis to be utilized in an integrated fashion, a set of alternative management prescriptions must be developed based on all resources*, and each functional analysis must identify the production response to all of those prescriptions. In some cases, production responses may be zero or negative.

(2) The land and water geographic unit upon which the production matrix is based is the same for all functional analyses (for all rows). This is obviously necessary because the potential management prescriptions must apply to a given "type" of land that will have particular production responses. A different matrix would have to be derived for each "type" of land that is of interest.

(3) The entries in each row are determined solely by the management prescription, and are not affected by the entries in other rows. This is necessary since each functional analysis will not be privy to the expected outputs of other functional areas. If various combinations of outputs are possible under a given management prescription, then the matrix is structurally inadequate. It may, however, serve as an approximation.

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*This in itself is a substantial undertaking.

Production Information

Given these three assumptions, each row in the matrix is separable and independent. That is, the production information in each row is unaffected by the information in other rows, so each row can be identified separately and independently in functional analyses. The first two assumptions can be met through design of the analysis, but the tenability of the third assumption is determined by the nature of the biological production unit. Violation of this third assumption could be ameliorated by iterative revision of functional output (row) estimates as they are "put together" in the matrix. This is the approach used by an interdisciplinary team; the first step is for each functional specialist to make functional estimates and the second step is to resolve across-functional inconsistencies and synergisms.

In addition to the "Product" rows in the production matrix (Figure 12), the "environmental quality outputs" rows must also be defined. These will be environmental quality indicators such as water sedimentation and species diversity. These indicators relate to the condition of the production unit (ecosystem) rather than harvestable outputs, so they should be analyzed in a separate, non-functional effort. All three assumptions must hold for this effort as well as in the functional analyses on the "Product" rows.

Figure 13 depicts an idealized organization of functional and multiresource analyses which utilizes the matrix structure to integrate functional production information and ecosystem condition information. To reiterate, functional analyses must be designed so that they are consistent in terms of management prescriptions considered and the land and water types considered.

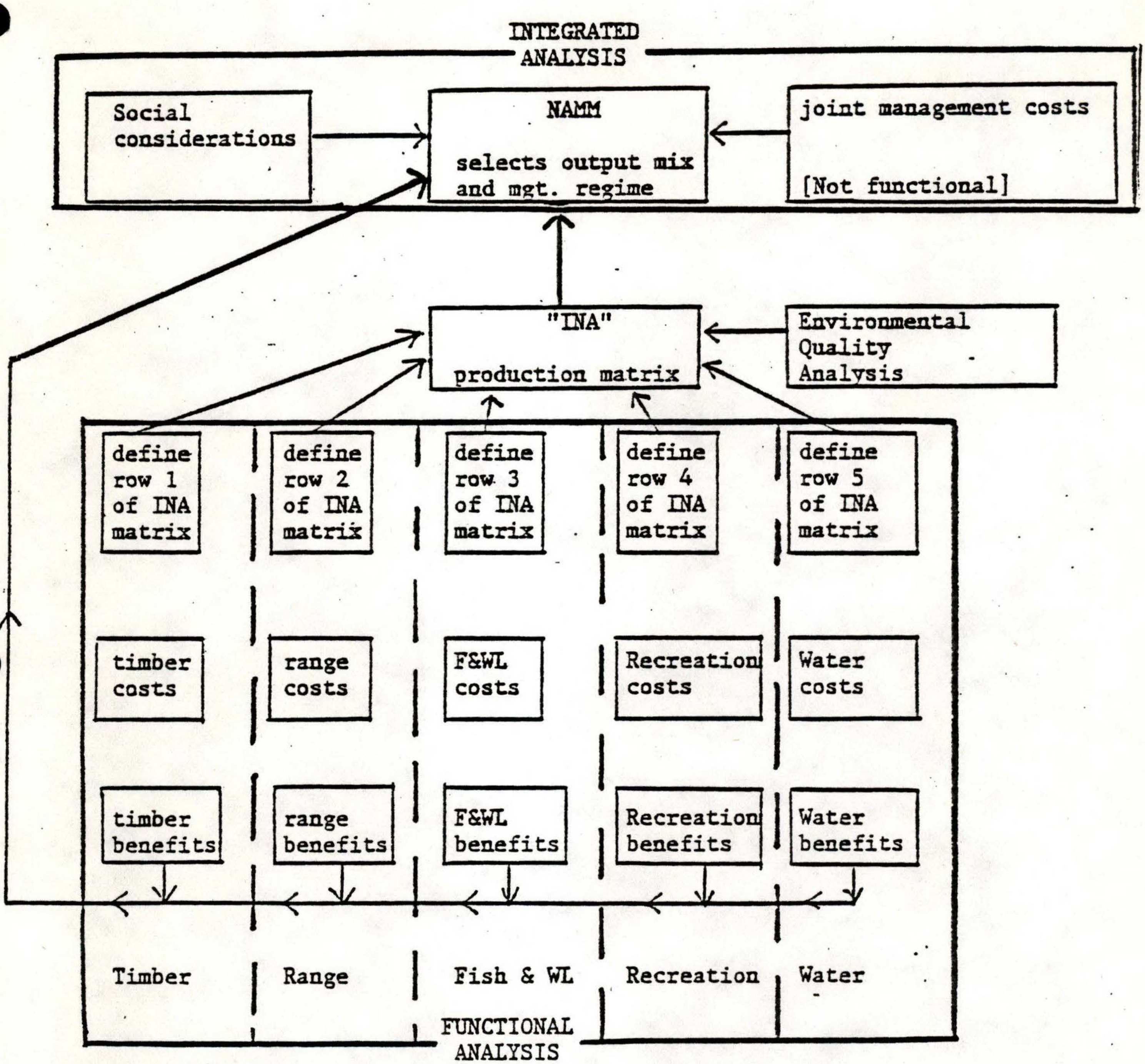

Figure 13. Organization of functional analyses in integrated analysis.